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Energy Procedia 17 (2012) 266 – 272

Energy Procedia

2012 International Conference on Future Electrical Power and Energy Systems

Image Processing in the Monitor of Boiler Drum Water Level on Power Plant

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Abstract

The measurement of power plant boiler drum water level has important significance. In this article, a new approach of estimating the position of steam-water with the image processing technology was proposed. Firstly the quality of images should be improved by using image preprocessing. Then the height of water level gauge should be determined according to the process of binary and edge extraction. This method is proved accurately in estimating drum water level through the results of experiments. And it has applications on power plant.

*Keywords:*boiler drum water level; image processing; preprocessing;

1. Introducetion

Measuring device of power plant boiler drum water level is an important instrument of boiler operation. The situation whether it could measure the real drum water level, has direct relation with unit safety operation [1]. Since rational allocation of measurement, control and protection system of drum water level is an important measure to ensure boilers' safety operation, the steam-water separating effect of steam-water separating device will be affected by exorbitant water level, to increase saturated steam's humidity and salt content of boiler output, and cause the flow path of super heater and turbine scaling, so that overheating of super heater's tube wall even tube explosion will be induced. Water impingement of turbine will be produced and destruction will be brought, if the water level is seriously too high. The safety of boiler water circulation will be affected, and overheating of partial water wall tube will be caused if water

 doi:10.1016/j.egypro.2012.02.093

level is too low. Boiler will explode if water is seriously short. Therefore, it has important significance in measuring the drum water level accurately to make sure the level is kept in prescribed limit.

Research about boiler drum water level is a hot spot, which focus on measurement methods and measuring devices. According to the situation of the water level image is too fuzzy shown in industrial television, and usually the interface of steam-water couldn't be judged in current monitoring of drum water level. The technology of image processing and the monitoring of boiler drum water level could be combined. Then corresponding process of water level image could be done based on digital image processing method, so that display quality of image is improved. At last, the value of water level is obtained from image, in order to help the operating personnel to judge the accurate value of water level.

2. Frame Preprocessing

The purpose of image preprocessing is to removal the noise in the image, making the image clear and the margin sharp which contain water level gauge, so as to improve the accuracy about the extracting resign of water level gauge. There are three steps as follows: image increasing, smoothing processing and sharpening processing.

Image increasing

First it is conducted image increasing processing before smoothing processing. Image increasing divided into spatial domain method and frequency domain method, spatial domain method is used to increase the pixels of image, and it could be defined as follow formula:

$$g(x,y) = T(f(x,y)) \tag{1}$$

f(x,y) represents original input of water level image, grey range is [m， M], g(x ,y) represents water level image after processing, the grey transform enhancement could be described as follow:

$$g(x,y) = (N-n)[f(x,y)-m]/(M-m)+n \tag{2}$$

Then the contrast ratio between target region and background region in the image could be increased.

Smoothing processing

Then executes smoothing processing is the enhanced image. The purpose of image smoothing processing is to reduce and eliminate the noise contained in the image, so as to improve the quality of image, and beneficial to extracting object characters to analysis. Local operators is used to noise image in classical smoothing processing, only some pixels in its local small neighborhood are processed when undergoing smoothing processing on one pixel, the advantages is high calculation efficiency and parallel processing a series of pixels. Neighborhood averaging is used to conduct smoothing processing on image in the article.

Neighborhood averaging is a partial processing algorithm in spatial domain. as for the pixel at the position (i, j),its gray value is f(i,j),and its gray value is g(i,j) which is determined by the average gray of several pixels at the neighborhood of pixel (i, j) including (i, j) itself after smoothing processing. The smoothed pixel gray value could be obtained by follow formula [2]:

$$g(i,j) = \frac{1}{M}\sum_{(x,y)\in A} f(x,y) \qquad \text{x,y=0,1,2,⋯,N-1} \tag{3}$$

A represents a point set in a field whose center is (i, j), M represents the total number of pixels in A. the smoothing result of neighborhood averaging is related to radius of the field, the larger the radius is, the fuzzier the smoothed images are:

$$g(i,j)=\begin{cases}\dfrac{1}{M}\sum\limits_{(x,y)\in A} f(x,y) & \left|f(i,j)-\dfrac{1}{M}\sum\limits_{(x,y)\in A} f(x,y)\right|>T \\ f(i,j) & \left|f(i,j)-\dfrac{1}{M}\sum\limits_{(x,y)\in A} f(x,y)\right|\le T\end{cases} \quad (4)$$

The advantages of neighborhood averaging is the is simple algorithm and the fast calculation, the main disadvantages is making the image fuzzy when reducing noise, especially at the edge and the details, the larger the field is, the fuzzier the images are. In order to reduce fuzzy distortion as far as possible, the criterion given above (formula (4)) could be used to conduct image smoothing processing, in this formula; T represents a defined nonnegative threshold value, which could be determined by general features or local features of the image. Those points are noise processed when the difference value between them and their neighborhood exceed threshold value T, otherwise those pixels gray value is still remained. The fuzzy degree of the smoothed image could be reduced through this way.

Sharpening processing

In order to increase the edges and details of the image contains water level gauge, highlight the information of the edges, and beneficial to binary, smoothed images are sharpening processed. This sharpening processing not only can be performed in spatial domain, but also can be performed in frequency domain. The space differentiation is used in this article. The edges of water level gauge could be enhanced and the gray field of slow transformation could be decreased through sharpening because of the response strength of differential operator is related to the mutation degree of the point in the image. The ability of enhance details formed by second order differential is better than first order differential, it could generate double response to stepped changes at gray level, so Laplace single mask could be used to carry on sharpening processing.

The definition of discrete form about two-dimensional Laplace transform is:

$$\nabla^2 f=[f(x+1,y)+f(x-1,y)+f(x,y+1)+f(x,y-1)]-4f(x,y) \quad (5)$$

The coefficient of single mask could be derived as follow [3]:

$$g(x,y)=f(x,y)-[f(x+1,y)+f(x-1,y)+f(x,y+1)+f(x,y-1)]+4(x,y)=5f(x,y)-[f(x+1,y)+f(x-1,y)+f(x,y+1)+f(x,y-1)] \quad (6)$$

The mask used in the transform is:

0	-1	0
-1	5	-1
0	-1	0

The edge part of the image can be enhanced after Laplace single mask sharpening transforming.

3. BinarY

Binary algorithm

The thought of discriminate analysis is that: a threshold should be set, to make sure the variance between two parts of histogram divided in this threshold is maximal, so that the problem of threshold selection converts into the problem of maximum value solution.

The boiler high water level gauge shows water level with two kinds of colors, according to different refractive indexes when the light is entering into steam and water from air. The gauge shows red in steam end and green in water end. In order to obtain the steam water interface, the method of binary can be adopted to distill the target image from the background. In this paper, a implementation method based on genetic algorithm has been proposed and then applied in discriminate analysis to binary process image, so that the problem of automatic threshold selection is solved preferably [4].

Genetic algorithm is a searching method based on natural selection and gene genetics theory. For the reason that the evolution principle of survival of the fittest in the natural biological system is absorbed, it can take robust search in a complicated space. Comparing with others optimization algorithm, its advantages show as follow:

1）Genetic algorithm operates not parameters, but the code of them;

2）Genetic algorithm parallel operates from several initial points to prevent the problem of local convergence effectively.

3）Genetic algorithm calculates according to target function, and has a low dependence of problems. The optimizing function has almost no restricted from genetic algorithm, and doesn't need to be continuous and differentiable, which can be explicit function or implicit function, so that the algorithm has a wide application.

4）Genetic algorithm confirms its searching direction according to the transition rule of probability instead of deterministic principle, and adopts a kind of heuristic search strategy instead of sightless exhaustive method or totally random test in solution space, which has a high searching efficiency.

5）he parallel computation can raise the computing speed greatly, which is suitable for optimization of large complicate problem.

The threshold selection function is set as the target function of problem, which is defined as :

$$\sigma^2(k) = [\mu\omega(k) - \mu(k)]^2 / \omega(k)[1 - \omega(k)] \quad (7)$$

In this formula, μ is the average gray of whole image; μ(k) is the average gray of threshold; ω is the whole probability of the gray value between 1 and k; Pi is the probability of each gray value; N is the total pixel number. Each value above as follows respectively:

$$\mu = \sum_{i=1}^{m} i \cdot P_i \quad \mu(k) = \sum_{i=1}^{k} i \cdot P_i \quad \omega(k) = \sum_{i=1}^{k} P_i$$

$$N = \sum_{i=1}^{m} n_i \quad P_i = n_i / N \quad (8)$$

Suppose the gray level of image as 1 – m, and ni as the pixel number with gray value i. σ2(k) is a discrete function, and the optimal threshold k* when σ2(k) is largest is supposed as the threshold for the binary according to genetic algorithm.

Noise removal after binarization

In order to removal or decrease the noise in the image and enhance the significant part of it, the binary water level gauge image should be noise removed through binary filter once again, because of the incomplete of the gray noise removing and the noise could be inducted during binary processing.

The binary hole could be filled, "burrs" and pixels whose value are isolated 1 could be removed through this processing, That is to say, it has filling and removing two algorithms, the rules about these two algorithms are described below respectively.

The first thing is the rules of filling. This algorithm set the value of pixel P which is satisfying the following conditions to be one:

1) The value of pixel P is 0;

2) There are three or more pixels whose value is 1 out of P's four neighborhood;

The next is the rules of removing. This algorithm set the value of pixel P which is satisfying the following conditions to be 0:

1) The value of pixel P is 1;

2) (p1+p2+p3)(p5+p6+p7)+(p3+p4+p5)(p7+p8+p1)=0;

3) P is not an endpoint.

The definition between p1 to p8 is showed as figure 1. The processes of filling and removing are given respectively in figure 2 and 3.

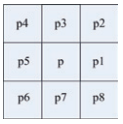

Figure 1. template

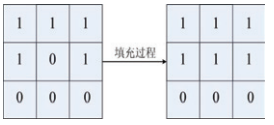

Figure 2. filling process

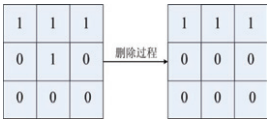

Figure 3. deleting process

Most holes and “burrs” are removed effectively from the original binary images after noise removing processing.

4. Edge Detection

The precision of steam-water interface could be improved if rough field that contains water level gauge could be extracted from the image at first and then use binary, because water level gauge images are rich in abundant background and environment information. The edge of water level gauge is approximately a straight line and at the position where discontinuous points are intensive, a better affection could be got by using Canny edge detecting algorithms based on optimization theory.

It proposed three indexes evaluating the performance of edge detecting, including large signal-to-noise ratio rule, high positioning accuracy rule and signal edge response rule, also mathematical method is used to derive the mathematical formula which determine the function performance index of image edge detecting systematically: signal-to-noise ratio SNR, detection precision L, and pseudo-boundary average distance M, the concrete algorithm is described as follow [5].

Smoothed image K(x, y) could be got by using one-dimensional gauss function (shown as formula (9)) filter, operating convolution by rows and columns to original image I(x, y) [6].

$$G = \frac{\exp(-x^2 / 2\sigma^2)}{2\pi\sigma^2} \qquad (9)$$

Filter structured by formula (8) is（0.0018 0.0215 0.0965 0.1592 0.0965 0.0215 0.0018）. Noise could be inhibited by using smoothing filtering; standard deviation σ in gauss function is used to control smoothing degree here. When σ is small, the filter is short, the computational complexity of convolution is low, and the positioning accuracy is high, but signal-to-noise ratio is low; on the contrary, when σ is large, the situation is opposite. According to actual situation, the parameter σ in gauss filter is valued equals to 1.

The next thing is to calculate the gradient magnitude M(x,y) and gradient direction H(x,y) of the smoothed image K(x,y) by using finite difference to first order partial derivative of 2×2 field.

$$M(x,y) = \sqrt{E_x(x,y)^2 + E_y(x,y)^2} \qquad (10)$$

$$H(x,y) = \arctan(E_y(x,y)/E_x(x,y)) \tag{11}$$

$$f_x = \begin{pmatrix} -0.5 & 0.5 \\ -0.5 & 0.5 \end{pmatrix} \quad f_y = \begin{pmatrix} 0.5 & 0.5 \\ -0.5 & -0.5 \end{pmatrix} \tag{12}$$

Ex and Ey represent the results of original image K(x, y) filtered by filters fx and fy by rows and columns respectively.

Then conduct non-maximum inhibition on gradient magnitude. If the gradient magnitude(x,y) of pixel point(x,y) than the gradient magnitude of two neighbor pixels at the gradient direction(parallel to the direction of H(x,y)), then this point will be judged as possible edge point.

Finally, using double threshold value method to detect and connect edges. Determine the upper and lower limit of threshold value t_{up} and t_{down} ($t_{up} > t_{down}$) about the set of possible edge points, the upper and lower limit of threshold value could be determined by the percentage of edges to the maximum points of gradient modulus. The high threshold value detection and the low threshold value detection could be got by using double threshold value treatment to non maximum inhibited images. Then connect the edges to the high threshold value detection, when they are connected to the end point, weak edge points are found in low threshold value detection to make up the marginal gap of high threshold value images.

5. Results of experiment

According to the method mentioned in this article, image containing water level gauge is preprocessed at first, the affection after processing is shown as figure 4

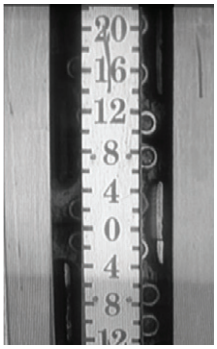

Figure 4. image preprocessing

Figure 5. edge detection

Then this image will be edge detected, which is shown as figure 5. The corresponding position of water level demarcation point could be got from the image by using binary after determining the field of steam-water interface, shown as figure 6.

Figure 6. binarization

6. Conclusion

The method of image process has been introduced in the monitoring of boiler barrel water level, which improves the image quality and extracts the steam water interface according to pretreatment, marginal extraction and binary. The experiment result shows that: this method has a preferably auxiliary function for the data reading of water level gauge, and has certain applicability.

Acknowledgment

This work is supported by Program of Shanghai Subject Chief Scientist with (09XD1401900), Supported by Shanghai Rising-Star Program (No. 10QA1402900) and Natural Science Foundation of Shanghai (No. 09ZR1413300).

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